Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

2026-26-0779 Published 01 Jun 2026

Electrical Harnessing in Satellite Launch Vehicles of ISRO – Methods for Sustainable, Safe and Reliable Systems

Nithish K S, Binny TR, and Praveen Kumar D S Vikram Sarabhai Space Centre

Citation: Nithish, K.S., Binny, T.R., and Praveen Kumar, D.S., "Electrical Harnessing in Satellite Launch Vehicles of ISRO – Methods for Sustainable, Safe and Reliable Systems," SAE Technical Paper 2026-26-0779, 2026, doi:10.4271/2026-26-0779.

Received: 26 Mar 2026 Revised: 21 Mar 2026 Accepted: 21 Mar 2026

Abstract

The electrical harness system of satellite launch vehicles functions as the backbone of spacecraft avionics; inter connecting subsystems through complex networks of wires and connectors. An electrical harness is a group of wires bunched together and terminated in connectors. The common insulations used for launch vehicle applications include PTFE, Polyimide, ETFE and TKT. The connectors used are of aerospace grade and connectors tailored for space applications. With over 5000 connectors and 200 km of cables constituting nearly 20% of vehicle mass, the design, fabrication, and sustainability of these systems are critical. The insulations of connectors inserts or the wires are critical for the durability of harness elements. Nevertheless, these insulations are non-expendable and pose disposal challenges and some releases toxic gases when burned or due to vacuum outgassing phenomenon. Also, the cadmium plating which is often used for the environmental resistance of connector shells presents additional risks to the working humans due to its carcinogenic nature and shows tendency to bloom out during storage. This paper presents the methodologies and innovations implemented to develop safe, reliable, and environmentally sustainable harness systems for current and future launch vehicles. Key advancements include the adoption of lean manufacturing practices for waste reduction, the replacement of hazardous cadmium-plated connector shells with stainless-steel alternatives, and the induction of TKT-insulated wires to prevent arc tracking and ensure human-rating compatibility. Additionally, lightweight composite connectors and micro-miniature interconnects are being qualified to support mass optimization in reusable launch vehicles. Through these strategic measures, the study demonstrates how the integration of sustainable materials, safety-oriented design, and process optimization can enhance the performance, safety, and environmental footprint of launch vehicle electrical harness systems.

Introduction

In satellite launch vehicles, the Electrical Distribution System (EDS) represents a critical infrastructure that ensures uninterrupted communication, control, power distribution, and health monitoring across vehicle subsystems. Electrical harnesses comprising bundled wires terminated with MIL grade connectors forms the backbone of this system. The more the complexity of the harness, the more the harness mass will be and which in fact is considered as nearly 20% of the total inertial mass of the launch vehicle. This mass, coupled with the irreversible nature of launch vehicle missions, necessitates rigorous design, qualification, and quality control measures.

As ISRO advances toward reusable launch vehicles and human spaceflight missions, electrical harnessing faces new performance, safety, and sustainability demands. The legacy materials and manufacturing practices require re-evaluation considering modern constraints, including reduced mass budgets, human-rating standards, environmental compliance, and reliability in extreme conditions.

To address these challenges, multiple initiatives have been undertaken:

- **Lean manufacturing and process optimization** have been applied to harness fabrication, significantly reducing material waste and operational inefficiencies.
- **Material substitution efforts** are underway to phase out hazardous substances such as cadmium plating on connector shells, with alternatives like stainless steel and zinc–nickel finishes being qualified.
- **Mass reduction initiatives** are being realized through the introduction of composite shell and micro-miniature connectors.
- For human rated launch vehicles, **TKT-insulated wires** have replaced traditional polyimide wires due

Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

to superior suitability against arc-tracking, abrasion, and smoke emission.

This paper presents the systematic implementation of the approaches mentioned above in the context of ISRO's satellite launch vehicle electrical harness, detailing the qualification processes, performance assessments, and design choices that enable enhanced safety, reliability, and environmental sustainability for future launch vehicle programs.

Lean-Driven Sustainability in Launch Vehicle Electrical Harness Systems

Lean manufacturing is a systematic production approach that aims to enhance efficiency by eliminating waste, improving workflow, and continuously improving the processes to deliver better customer value while preserving the desired level of product quality. This is achieved by applying lean principles, techniques, and tools to eliminate waste from a manufacturing cycle. The lean manufacturing process was first implemented in the Toyota Production System TPS which revolutionized the company's manufacturing process and then expanded all over the world. The advantages of Lean manufacturing are

1. Improves quality
2. Inventory management
3. Process improvement
4. Eliminate waste
5. Reduce time
6. Reduce total costs

The application of lean manufacturing principles in the field of satellite launch vehicle electrical harnessing has enabled significant improvements in process efficiency and resource utilization.

All harness components including wires, connectors, contacts, accessories, and consumables are sourced in compliance with established aerospace standards such as MIL (Military) and SAE (Society of Automotive Engineers) specifications. These components are selected for their exceptional reliability under extreme environmental conditions and are subjected to extensive quality assurance frameworks that include visual inspection, electrical characterization, mechanical integrity checks, and environmental durability testing.

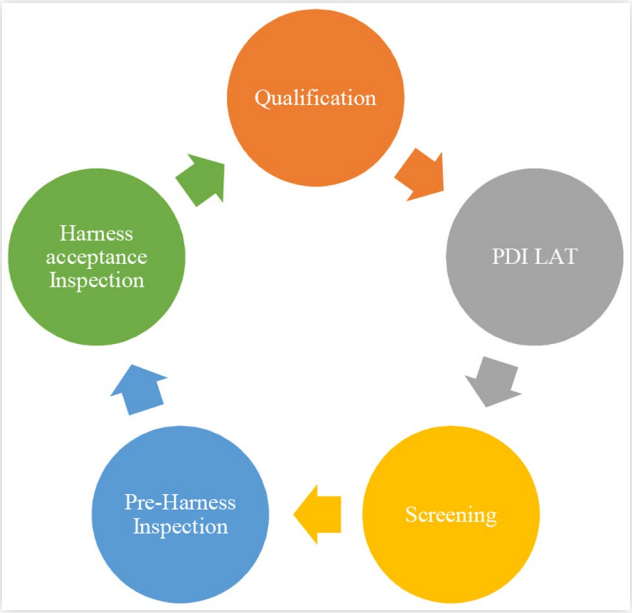
However, ensuring such a high level of performance and reliability comes at a significant cost. Aerospace-qualified components typically command prices several times higher often ranging from 5 to 100 times than their commercial grade counterparts due to stringent quality assurance, traceability, and environmental qualification requirements. Given the irreversible fabrication nature of electrical harnesses and the critical impact of any deviation on mission success, minimizing material wastage and optimizing resource utilization become imperative for sustaining both cost efficiency and reliability in aerospace production environments.

To ensure that only flight worthy components are integrated into the harnessing process, a standardized inspection and acceptance workflow has been established, comprising multiple validation stages. This multi-level validation framework not only reinforces quality but also ensures traceability and component level reliability in the overall robustness of the launch vehicle's electrical distribution system.

As shown above in figure 1a, each component undergoes a minimum of five stages of inspection and validation before being applied for flight use. However, the substantial effort and cost invested in procurement and screenings are often wasted when components are damaged due to inadequate awareness or improper handling by operational personnel. To prevent such losses, a systematic approach is required that monitors and quantifies wastage, identifies root causes, implements corrective and preventive measures, and continuously evaluates process performance for further improvement.

It was seen that lean principles being followed in manufacturing facilities had succeeded in bringing down the product realisation time and cost effectively without losing the quality of a product, thought process was initiated on implementing the lean management quality principles in the launch vehicle harness fabrication as well. In the electrical harness realization for launch vehicle programs, the complexity of operations spread across design interpretation, wire cutting, crimping, connector assembly, and testing creates multiple opportunities for inefficiency. High value materials, frequent design revisions, and stringent traceability requirements often lead

FIGURE 1a Inspection stages of a component



Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

to unavoidable wastage of resources if not systematically controlled. On realizing this challenge, a comprehensive lean management system was designed to monitor and minimize waste generation across all levels of harness fabrication and testing.

Lean Management System

Figure 1b illustrates the block schematic of the system proposed. The harnessing of the launch vehicle sub assemblies is carried out by multiple external agencies utilizing in-house facilities. The framework begins with the nomination of focal points from each harnessing team to coordinate and monitor lean activities. Awareness sessions are conducted to emphasize the importance of waste reduction and to communicate detailed implementation plans. The system includes dedicated facilities for waste collection, standardized documentation for tracking and analyzing wastage, weekly audits, and review mechanisms for continuous feedback. It also explores recycling opportunities and introduces recognition programs to motivate teams achieving consistent waste reduction.

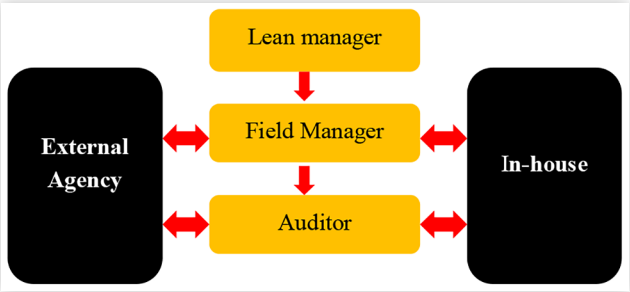
Methodology

Stakeholder Engagement and Awareness Implementation commenced with a brainstorming session involving all stakeholders, including engineers, supervisors, and technicians. A structured questionnaire was developed to promote self-assessment and generate awareness regarding existing inefficiencies. The questionnaire addressed critical aspects such as:

- Effectiveness of resource utilization;
- Volume and type of material being wasted;
- Cost and quality sensitivity of materials handled;
- Impact of rework and re-fabrication on schedule; and
- Possibilities for reuse and recycling of discarded materials.

Responses provided insight into the perception of waste at different organizational levels and established a foundation for data-driven improvement.

FIGURE 1b Block schematic representation of the system



Identification of Waste Sources The next phase involved mapping the production process to identify areas contributing to waste. The analysis adopted the **eight classical categories of lean waste**:

1. **Unnecessary transportation** – multiple material handlings and transfers between the facilities.
2. **Excess inventory** – accumulation of unused or expired components.
3. **Unnecessary movement** – inefficient workplace layouts causing unnecessary motion.
4. **Waiting** – idle time due to inspection delays or unavailability of facility.
5. **Overproduction** – production exceeding the immediate need.
6. **Overprocessing** – redundant steps beyond specification.
7. **Defects** – reworks and scrap due to non-conformances.
8. **Underutilized talent** – insufficient engagement of worker skills and creativity.

Each category was assessed through direct observation, feedback sessions, and audit findings from harness fabrication facilities.

Analysis of Resource Wastage

Wires and Cables Wire wastage was predominantly attributed to incorrect selection of type, gauge, or colour; cutting excess lengths; and over-stripping insulation. Frequent design revisions or changes in Electrical Interface Definition (EID) often rendered pre-cut wires unusable. In addition, defects during transportation and improper spool handling resulted in further loss.

Connectors and Contacts Losses in connectors and contacts occurred mainly due to improper crimping tool settings, usage of un-calibrated tools, and mishandling during insertion or extraction. In certain cases, design modifications during fabrication led to rejection of assembled connectors. Poor storage practices and environmental exposure also contributed to deterioration.

Harnessing Accessories and Consumables Improper planning and over-ordering of consumables such as heat-shrink sleeves, lacing cords, and identification markers led to excess inventory. Inadequate storage and non-adherence to shelf-life monitoring caused materials to expire before use.

Manpower and Facility-Related Issues Operational inefficiencies stemmed from inadequate skill levels, lack of training, and suboptimal work scheduling. Excessive movement of personnel and tools between bays added to non-productive time. Certain facilities lacked ergonomic layouts, proper lighting, or tool accessibility, further impeding productivity.

Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

Implementation of Lean Solutions

Process Standardization and Documentation A major focus area was establishing robust documentation and process discipline. Harness detail documents were revised to include exact lengths, connector types, and material specifications to prevent over-cutting of wire lengths and improper selection of wire types. Teams were instructed to always refer to the latest revision of production documents, verified through digital configuration management systems.

Tool Control and Maintenance To minimize defects arising from tool wear, periodic inspection and calibration schedules were enforced. Only qualified and QC-cleared tools were permitted for production use. Visual identification and tagging systems were introduced to differentiate between calibrated and non-calibrated tools.

Material Management and Reuse Dedicated bins were installed at workstations for collecting short wire lengths and unused connectors, enabling reuse in other subassemblies. Material expiry tracking was implemented through barcode-based inventory management to ensure timely utilization. Storage areas were redesigned for proper segregation of cleared and non-cleared items.

Facility Optimization Work bays were re-laid to minimize operator movement and handling. Flight-identical mock-up structures were introduced for ergonomic harness routing and to ensure dimensional accuracy. Sharp edges were masked to prevent insulation damage. Remote inspection capabilities were added to reduce travel delays for quality inspectors.

Human Resource Development Training sessions were conducted to enhance operator competence in tool handling, document interpretation, and lean principles. Supervisors were trained to act as lean champions responsible for daily oversight. A culture of "ownership for quality" was encouraged through cross-functional discussions and visual performance tracking boards.

Monitoring and Continuous Improvement

A structured monitoring mechanism was instituted through weekly audits focusing on material usage, facility cleanliness, and adherence to process standards. Each audit produced a set of corrective and preventive actions which were tracked until closure. Regular review meetings with working teams provided opportunities for knowledge sharing and iterative improvement.

Feedback from the shop-floor teams highlighted the value of real-time documentation, improved accessibility of materials, and enhanced awareness of cost implications. Additionally, a **recognition program** was introduced to reward teams demonstrating measurable waste reduction, fostering motivation and ownership across all levels.

Results and Discussion

Implementation of the lean management system on a sample space yielded measurable improvement:

- Reduction in wire and connector wastage by approximately 25–30% within six months.
- Improved on-time completion of harnessing activities due to reduced rework cycles.
- Enhanced traceability and accountability through standardized documentation and audits.
- Strengthened collaboration between design, quality, and production teams, leading to faster resolution of field issues.

Qualitative benefits included increased operator awareness, better workplace organization, and a visible cultural shift towards waste consciousness. The initiative demonstrated that even in high-precision aerospace environments, lean principles can be effectively tailored to achieve sustainable efficiency gains.

Connector Mass Optimization for Enhanced Payload Capacity in Launch Vehicles

The mass of the launch vehicle systems has direct correlation on the weight of payload which can be taken to the intended orbits. In expendable launch vehicles, the spent stages will be separated as per the mission design and thus attains the velocity and attitude for placing the satellite in the precise orbit. But for re-usable launch vehicles, it has to carry the entire mass till it reaches back to earth after placing the satellite in the orbit. Mass of the vehicle is a big concern especially for the reusable launch vehicles. One of the solutions to this issue is usage of light weight connectors such as composite shell and micro miniature connectors which are functionally meeting all the equivalent performance standards of conventional aerospace connectors in use.

Samples of circular connectors manufactured with shells made of composite materials were collected from various vendors for initial assessment and comparison. It is noted that a minimal gain of 25-35% weight savings is achievable in most common variants and even 75% reduction is noted for some variants as shown in figure 2a in comparison to the equivalent conventional types.

The electrical and mechanical performances of all the composite shell connectors were seen to be with the existing Aluminium shell connectors on initial assessment. The connectors are already confirming to the MIL specification MIL-C-38999 and some are already being supplied to aviation industry.

Other initiatives in this approach are the proposed use of micro-38999 circular connectors and micro-D sub rectangular connectors (see figure 2b). The connectors are being qualified and induction process in the avionic

Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

FIGURE 2a Weight comparison (courtesy: Souriau India)

FIGURE 2b Micro-D connectors (courtesy: Amphenol Interconnect India)

packages as a replacement of the existing D sub connectors in underway. Factory crimp connectors with pigtail are already available with the party and field crimpable connectors are being developed and which will obviously bring down the overall mass of the harness. Efforts are initiated towards indigenously developing these connectors.

Transitioning to Environmentally Compliant Connector Plating Materials in Launch Vehicle Electrical Harnessing

D-sub miniature (D-sub) rectangular connectors, compliant with the MIL-C-24308 standard, are cornerstones of avionics interconnect systems in both launch vehicles and satellite platforms. Their compact form factor, lightweight construction, and high electrical performance make them particularly well-suited for dense aerospace environments where space, mass, and functionality are tightly interdependent. In a typical PSLV (Polar Satellite Launch Vehicle), the wiring architecture incorporates approximately 2,400 connectors of which over 70% are D-sub types underscoring their pervasive role in ensuring signal integrity and operational reliability.

In launch vehicle applications, especially those involving aggressive environmental conditions, the use of cadmium-yellow passivated mild steel shell connectors (Class G, finish F) is deeply rooted in their established resistance to corrosion and electromagnetic shielding capabilities. Conversely, for satellite-based systems where prolonged exposure to vacuum and radiation necessitates ultra-clean material interactions gold-plated and stainless-steel shell variants are favoured for their superior inertness and low outgassing behaviour.

These connectors are stored in controlled, bonded inventory environments in adherence to military-grade logistics and traceability protocols. However, cadmium-plated connectors are not without serious drawbacks. A significant risk associated with their storage is the formation of “cadmium bloom,” a surface corrosion phenomenon exacerbated in enclosed wooden or poorly ventilated containers. The resulting white, powdery deposit is a toxic cadmium compound that easily becomes airborne and can be inhaled. Even minimal exposure to cadmium can be dangerous, as the element is recognized as a carcinogenic substance that can accumulate in the body and cause serious long-term respiratory and health complications.

This dichotomy between performance reliability and material safety has intensified efforts to replace cadmium-based finishes in space-grade connectors with safer alternatives, without compromising functional and environmental resilience. The transition toward such replacements is now a key focus in space electrical system sustainability and workplace safety.

Rationale for Using Cadmium-Plated Connectors

Cadmium plating is widely employed in aerospace and military-grade electrical connectors owing to its unique combination of protective and functional properties. The coating provides excellent corrosion resistance, typically withstanding 500–1000 hours in neutral salt spray tests, thereby ensuring long-term durability in harsh environmental conditions. In addition, cadmium offers superior electrical conductivity, contributing to effective electromagnetic interference (EMI) shielding performance. Its inherently low coefficient of friction facilitates smooth mating and demating of connectors, reducing wear and the potential for mechanical damage. The non-reflective surface finish is particularly advantageous in military applications, where optical signature control is critical. Furthermore, the plating exhibits good adhesion characteristics, enhancing the performance of subsequent coatings or sealants. Despite the availability of alternative coatings, cadmium remains a cost-effective and performance-proven choice for high-reliability aerospace electrical systems.

Despite these advantages, cadmium plating presents notable environmental and health concerns, especially in storage and handling conditions. The following case study highlights an incident that underscores the risks

Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

associated with cadmium-plated connectors in launch vehicle systems.

Case Study-Cadmium Bloom in Launch Vehicle Harness Systems

During the inspection of a ground system electrical harness elements associated with a rocket launcher, white powder deposits were noticed on the shell– internal and external surfaces of all D sub connectors irrespective of their make, type, and date code of manufacturing. The harness elements were recently fabricated and the electrical component with this harness was assembled on a painted metallic box.

Analysis

- Samples of affected connectors were removed from the circuit and given to the analytical agencies to identify and find out the chemical composition of the white deposit.
- Fresh connectors from different batches were taken and positioned at different known environments to experimentally recreate the observation.

Experimentation Connectors from different batches and makes as shown the Fig 3 (a) were kept in the following environments.

- Open air
- Closed aluminium box
- Closed enamel painted aluminium box
- Closed plastic container

Observation A series of controlled observations were conducted to investigate the influence of storage environment on the surface integrity of cadmium-plated connectors. The connectors were periodically inspected at intervals of three days to assess any visible changes or onset of corrosion. Connectors stored inside an enamel-painted metallic box exhibited the formation of a white powdery substance on the outer shell surface after the initial inspection period. These affected samples were subsequently subjected to chemical analysis to determine the composition of the deposit.

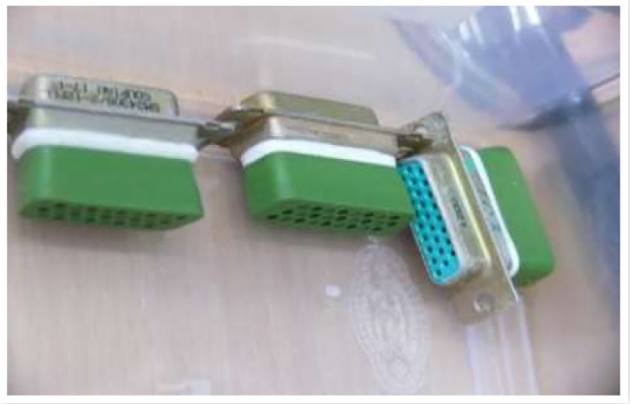
In contrast, connectors kept in open-air conditions showed no visible corrosion or surface degradation, even though the surrounding atmosphere was saline due to the facility's proximity to the sea. This finding indicated that the corrosion or surface bloom was not directly related to environmental salinity but to the specific storage conditions.

To validate this hypothesis, additional tests were conducted using new connectors placed in sealed plastic containers; one was containing enamel paint (Refer Fig 3b) and another containing thinner. After three days, connectors stored in proximity to enamel paint developed a similar white powdery film on their surfaces (Refer Fig. 3c), while those stored with thinner remained unaffected. This consistent observation strongly suggested that volatile organic compounds or chemical vapors emitted from the enamel paint interacted with the cadmium plating, resulting in a phenomenon commonly known as **cadmium bloom**.

FIG. 3A Connectors for experiment

FIG 3B Connectors with enamel paint on plastic container

FIG 3C White powder on connector shell kept along with enamel paint.



Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

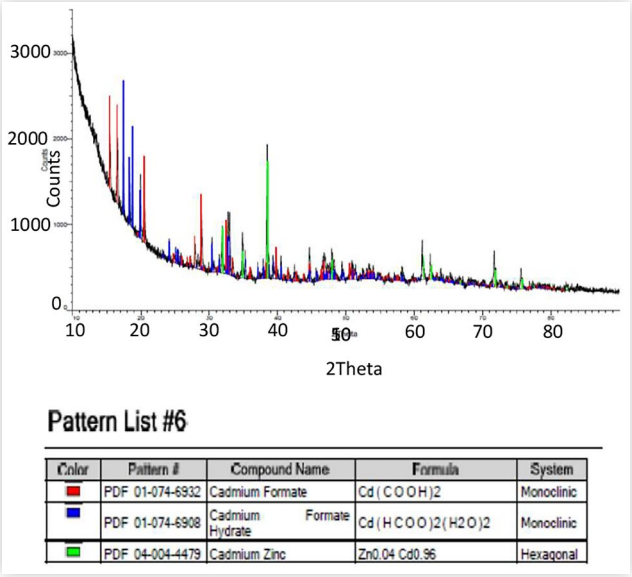
FIG. 3D White powder on harness connector kept in almirah.

Further supporting evidence was obtained from field observations, where harness connectors stored in recently enamel-painted cabinets exhibited the same white powdery deposits (As shown in Fig. 3d). These findings confirm that the reaction between cadmium and volatiles released from enamel paint is the primary cause of surface blooming, rather than environmental humidity or salinity. The study thus establishes that enamel-painted environments can significantly compromise the surface integrity of cadmium-plated connectors during storage. Appropriate preventive measures, such as isolating connectors from freshly painted enclosures or allowing adequate curing and ventilation time before storage, are therefore essential to maintain connector reliability and appearance.

Spectroscopy Result (XRD Analysis) XRD analysis was conducted on the white powder deposits as well to analytically figure out the chemical constituents. ***Results revealed that the white deposit is Cadmium Formate*** (Refer Fig 3e)**.**

Spectroscopic analysis and experimental observations clearly shows that the corrosion observed on the cadmium surface initiated from its interaction with the painted environment. The paint was found to release formic acid vapours, resulting in a localized acidic atmosphere. This acidic environment aided the chemical interaction between formic acid and cadmium, leading to the formation of cadmium formate, manifested as a whitish bloom on the connector shell. Therefore, it was concluded that improper storage in such environments accelerates corrosion and surface degradation of cadmium coated components. Appropriate measures were implemented, including the establishment of controlled storage conditions and the dissemination of awareness regarding potential medical and environmental hazards associated with cadmium corrosion products.

FIG. 3E XRD Analysis report of the connector sample with cadmium bloom formation (VSSC internal Report No. AIAS/117857)



Sustainable Alternatives for Cadmium Plating

Various literature surveys are done for finding an alternate finish for the military/aerospace grade connectors as a replacement of the cadmium plating on aluminium, mild steel, and composite connector bodies. The findings are listed here.

- Nickel-Fluorocarbon (PTFE) - SAE AMS-2454
- Zinc-Aluminum / Zinc-Iron/ Zinc-Nickel (5-20% nickel) - ASTM B841, AMS2417
- Tin /Tin-Zinc (MIL-C-24308)
- Nickel
- Pure Dense Aluminum - Mil-DTL-83488,
- Stainless steel (MIL-C-24308).

As per the latest revision of MIL-C-24308 specifications, Pure Dense Aluminum, Nickel-Fluorocarbon, stainless steel, Zinc and Zinc-Nickel plated connectors are included for usage in space applications. The mechanical and electro chemical properties of both materials are matching and are compatible with cadmium plated connectors as well.

From the quoted studies and surveys, passivated stainless steel connectors (Fig. 3f) were considered as a replacement to the existing cadmium plated mild steel shell connector considering the availability, processing easiness, and cost. The development and initial assessment of the connector have been carried out and are satisfactory. Further qualification process in underway.

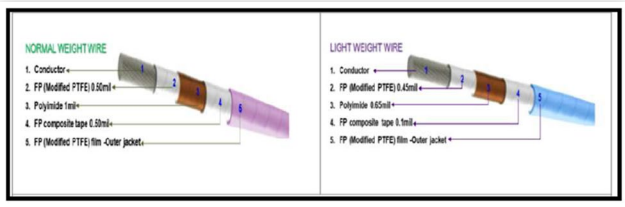
Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

FIG 3F Stainless steel shell connectors (grommet type and non-grommet type).

Safe Wires and Cables for Harness in Manned Mission Systems

The main component of the electrical harness is the wires and cables. The insulating materials used for the core wire outer insulations and for the outer jacketing of cables with multiple cores may pose hazards viz. burning, charring, smoke release, outgassing, arc tracking, etc. due to the damages. The commonly used insulations for aerospace cable harnesses are Poly tetra Fluoro Ethylene (PTFE), Polymide, Ethylene Tetra Fluoro Ethylene (ETFE) and the type of constrictions were tape wrapped or extruded form. Among these, the Polyimide insulated wires has highest insulation withstanding strength per unit thickness, high thermal resistance, low outgassing in vacuum. But it has the shortcomings of poor mechanical strength, insulation cracking, and arc tracking phenomenon. As the arc tracking property can result in catastrophic damages of electrical insulations leading to total loss of electrical cables, the polyimide insulated wires and cables are not to be used for any space applications with human presence. With due consideration of above criticalities and based on the references from various technical studies and analyses, an alternate insulation material with all good properties of polyimide insulation and protection against the arc tracking phenomenon was identified. The Teflon-Kapton-Teflon (TKT) insulation system, consisting of a Polymide core sandwiched between modified PTFE (FE) layers offers an improved balance of performances and parameters, making it suitable for human-rated applications. The constructional details of the TKT wire are shown in Fig. 4a. The PTFE outer layers improve flexibility and reduce surface energy,

FIGURE 4A Constructional feature of TKT insulated wires-Normal & light weight categories (Source: Report No.ISRO-URSC-TR-1649, dated Dec 2021)


NORMAL WEIGHT WIRE
1. Conductor
2. FP (Modified PTFE) 0.50mil
3. Polyimide 1mil
4. FP composite tape 0.50mil
5. FP (Modified PTFE) film -Outer jacket
LIGHT WEIGHT WIRE
1. Conductor
2. FP (Modified PTFE) 0.45mil
3. Polyimide 0.65mil
4. FP composite tape 0.5mil
5. FP (Modified PTFE) film -Outer jacket

thereby improving arc-tracking resistance and abrasion durability. For man rating of the conventional launch vehicle systems as human rated launch vehicle systems, the systems must have adequate design margins, failure tolerances, human safe factors, crew safety mechanisms and measures and a final certification process for the effective implementation of human rating. Here we are addressing only the electrical harness and mainly focusing on the wires and cables for human rated launch vehicle.

The main properties of TKT insulated wires and cables are

- Arc-track resistant
- Abrasion resistant
- More heat tolerance
- Resists smoking when burning
- Combines the excellent Electrical and Mechanical properties of Polyimide with the resistance of PTFE insulation to fluids and chemicals.
- Has all positive aspects of Polyimide (light weight, no fumes when burning) and has no demerits of Polyimide
- In usage from 1992 on all aerospace systems with human presence.
- ***Meets the FAR 25 requirements and no known problems.***
- ***Categorized as SAFE WIRE in the aviation safety analysis study on aircraft wires.***

The TKT insulated wires and cables are fabricated and governed by the applicable specifications of the Military standards specification (MIL) and Society for Automotive Engineers (SAE) professional bodies. These include the specifications for the product and test requirements, test methods for Qualification, Lot Acceptance tests for the different categories of TKT insulated wires based on the conductor material (Tin/ Copper/ Nickel), type of conductor (Soft Annealed / high strength alloy), sizes of wires, Normal and light variants of TKT insulations.

Qualification Tests

The qualification process of TKT insulated wires and cables for the human rated and launch vehicle and

Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

GAGANYAAN crew/ service modules was completed as per the SAE specifications – SAE-AS22759/ 80 to 92. The test matrix included detailed tests for evaluation of each of the physical, mechanical, environmental, electrical, and chemical properties. After proper scrutiny of these test results, additional testing on the manned mission system requirements like radiation resistance, outgassing, atomic oxygen resistance was also done and the use of TKT insulated wires and cables were cleared for flight systems for human space missions of ISRO. For the **Atma Nirbhar Bharat** initiative, an indigenous source was identified to have proper control and quality assurance philosophies, though there are many imported sources available. The TKT insulated wires and cables are in use at all stage electrical interconnections of the upper stages of launch vehicle and in the crew module systems for the human space mission of ISRO.

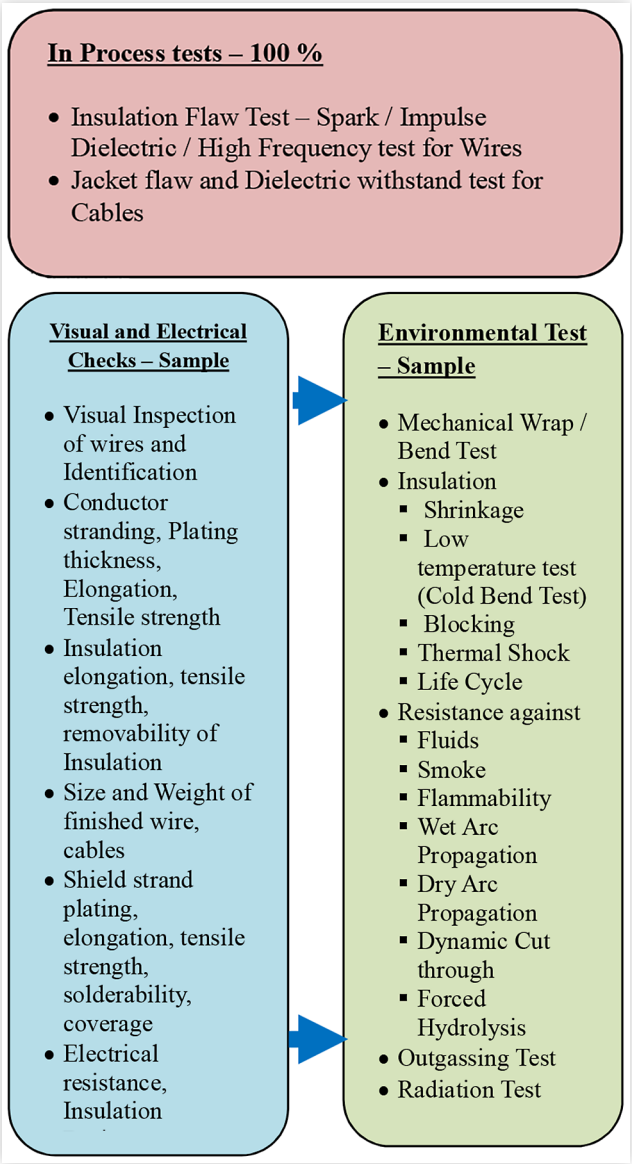
Satisfactory performance during flammability test, smoke test, wet arc propagation, dry arc propagation, immersion test (20 hours), humidity test, abrasion resistance test, Anthony brown tests etc done on the samples provided confidence on the safety and performance aspects under various environmental conditions. In the arc propagation tests – wet and dry, arc tracking resistance of the wire samples were demonstrated for intentional arc fields created by insulation damages on the wire samples excited with high voltage, high frequency voltage and current signals for a continuous duration of 24 hours. In the smoke resistance test, the conductors were passed with currents for duration of 30 minutes causing the heating of wire insulation to the rated levels of temperature and absence of smoke and electrical integrity of the wire, subsequent to the test was ensured. Tests for radiation resistance were also done for validating the usage plan in low earth orbit applications with required levels of radiation demanded by the intended human space mission program. In this test, the electrical and mechanical characteristics of the wires are evaluated and compared before and after the application of radiation dosage. All test results were critically reviewed in the review forums and was cleared based on the satisfactory performance and audit results.

Fig. 4b depicts the qualification test carried out to assess the overall workmanship and quality compliance of the manufactured cable assembly. The test procedure involved verifying the insulation integrity across the entire cable length to ensure continuity, dielectric strength, and absence of insulation breakdown prior to dispatch. In addition to the electrical verification, visual inspection and environmental screening were conducted on a sampling basis in accordance with the approved test plan. These checks were intended to confirm conformity to design specifications, workmanship standards, and environmental durability requirements as stipulated in the applicable quality assurance documentation.

Quality Assurance measures done in house

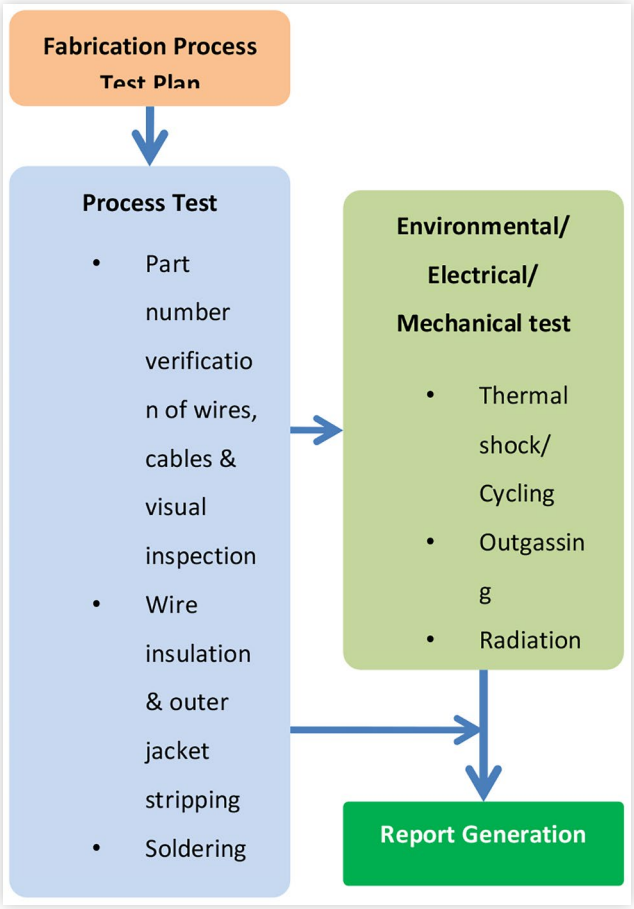
The wires / cables from the new vendor were initially evaluated in the ground interfaces like test harness, simulation deck harness etc. for assessing the field usage feedback on workmanship and harnessing applications. Towards this, the tool selections were studied and the correct tool with required settings was documented and all work-force were trained and evaluated on the job. Detailed assessment on the fabrication process and compatibility tests and inspection methodologies was

FIGURE 4B Test details for quality assessment at manufacturer works.


In Process tests – 100 %
• Insulation Flaw Test – Spark / Impulse Dielectric / High Frequency test for Wires
• Jacket flaw and Dielectric withstand test for Cables
Visual and Electrical Checks – Sample
• Visual Inspection of wires and Identification
• Conductor stranding, Plating thickness, Elongation, Tensile strength
• Insulation elongation, tensile strength, removability of Insulation
• Size and Weight of finished wire, cables
• Shield strand plating, elongation, tensile strength, solderability, coverage
• Electrical resistance, Insulation
Environmental Test – Sample
• Mechanical Wrap / Bend Test
• Insulation
▪ Shrinkage
▪ Low temperature test (Cold Bend Test)
▪ Blocking
▪ Thermal Shock
▪ Life Cycle
• Resistance against
▪ Fluids
▪ Smoke
▪ Flammability
▪ Wet Arc Propagation
▪ Dry Arc Propagation
▪ Dynamic Cut through
▪ Forced Hydrolysis
• Outgassing Test
• Radiation Test

Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

FIGURE 4C Test details for in-house quality conformance assessment



done at different work centres in VSSC, URSC, HSFC on various samples of TKT insulated wires and cables. These included mainly the visual checks of conductors, insulation, shielding, jacketing, marking and workmanship aspects of crimping and soldering activities, tensile strength tests, wet probe tests, effect of adhesive applications, effect of solvent dipping, thermal shock/ cycling, vibration testing, thermal outgassing, radiation tests etc. The recommended guidelines and precautions to be followed during harnessing, inspection, handling activities, and the various criteria for acceptance / rejection of the systems were clearly documented and circulated to all the team members.

Challenges and Trends

The availability of indigenous manufacturing sources in India that comply with stringent aerospace qualification standards for connectors and wires remains limited. This constraint results in elevated programme costs and dependence on a small number of qualified suppliers, leading to restricted competition. The identification and qualification of alternate sources that meet established reliability, quality, and traceability requirements is particularly challenging within the current Indian aerospace manufacturing and testing ecosystem, where the pool of capable vendors is limited. However, initiatives such as Atma Nirbhar Bharat and increased participation of global aerospace manufacturers in India are expected to strengthen the industrial base. These developments are likely to facilitate the induction of additional qualified suppliers, promote competitive sourcing, and enable cost optimization without dilution of quality or mission assurance requirements.

The approval and certification process for introducing new sustainable and reliable products into operational launch vehicle systems is inherently rigorous and time-consuming. This is primarily due to the conservative design philosophy adopted for flight-proven systems, where any change carries significant mission risk and involves multiple stakeholders, including external customers. To mitigate these challenges, a piggyback in-flight validation approach can be adopted, wherein new products are qualified under actual flight environments without impacting primary mission objectives. Such an approach enables progressive confidence building and reliability assessment while maintaining mission safety.

Recent trends in satellite launch vehicle development programs emphasize the adoption of new materials and components that address sustainability and reliability requirements, particularly in new design and development phases. In contrast, the incorporation of these products into existing operational systems remains a major challenge due to stringent qualification requirements, risk considerations, and lifecycle cost implications.

Conclusion

This paper demonstrates key advancements toward sustainable, safe, and reliable electrical harness systems for ISRO launch vehicles. Implementation of lean manufacturing reduced material waste and improved process efficiency without compromising quality. Replacing cadmium-plated connector shells with stainless-steel alternatives eliminated toxic exposure risks while maintaining corrosion resistance. The introduction of lightweight composite and micro-miniature connectors achieved up to 25% mass reduction, directly enhancing payload capacity for reusable vehicles.

Qualification of TKT-insulated wires ensured superior arc-tracking resistance, mechanical strength, and thermal stability, meeting the stringent requirements of human-rated missions. Together, these initiatives establish a sustainable and high-reliability framework for future space systems, reinforcing India's self-reliance and commitment to environmentally responsible aerospace engineering.

Downloaded from SAE International by Southwest Research Institute, Monday, July 27, 2026

References

1. Landau, P., "What Is Lean Manufacturing? Definitions, Principles &Techniques," https://www.projectmanager.com/blog/what-is-lean-manufacturing, published on October 1, 2024.
2. Brooman, E.W., "Alternatives to Cadmium Coatings for Electrical/Electronic Applications," published on February 1993.
3. McMillan, V.C., "Electro Deposited Zinc-Nickel as an Alternative to Cadmium Plating for Aerospace Application," NASA TM-103551, July 1991.
4. Glenair QwikConnect magazine, volume 27, Number 2, published on April 2023.
5. EATON 8D Series Composite Connector Datasheet- "38999 Series III Composite Connectors."
6. MIL-C-24308H, published on February 2018
7. MIL-W-22759&SAE-AS22759/ 80 to 92
8. NASA-STD 8739.4: 'CRIMPING, INTERCONNECTING CABLES, HARNESSES, AND WIRING
9. ISRO-PAX-300, Issue.05, November 2012: "Workmanship Standard for Fabrication of Electronic Packages."
10. "Report on Fabrication Process Compatibility Tests of TKT,"
    Report No. ISRO-URSC-TR-1649, dated December 2021.

Contact Information

Nithish K. S, QCD/QMPG/MVIT, VSSC, ISRO, Thiruvananthapuram
ks_nithish@vssc.gov.in, nithishsivam@gmail.com
Mob. +91-9895388133

Definitions/Abbreviations

ISRO - Indian Space Research Organisation
PTFE - poly tetrafluoroethylene
ETFE - Ethylene trafluoroethylene
TKT - Teflon-Kapton-Teflon
EDS - Electrical distribution system
TPS - Toyota production system
MIL - Military
SAE - Society of Automotive Engineers
EID - Electrical interface definition
QC - Quality control
VSSC - Vikram Sarabhai Space Centre
URSC - U R Rao Satellite Centre
HSFC - Human Space Flight Centre

© 2026 SAE International and SAE INDIA. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, or used for text and data mining, AI training, or similar technologies, without the prior written permission of SAE.

Positions and opinions advanced in this work are those of the author(s) and not necessarily those of SAE International. Responsibility for the content of the work lies solely with the author(s).

ISSN 0148-7191